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Improving Soil Erosion Prevention in Greece with New Tools

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Abstract
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Keywords
climate change, integrated information system, automated measurements, continuous measurements, dissemination

Disciplines
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Improving Soil Erosion Prevention in Greece with New Tools

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Abstract

Unsustainable anthropogenic activities such as agriculture and urbanization have caused excessive erosion rates that exceed soil formation rates. The Mediterranean region has and continues to experience severe erosion because of the inappropriate agricultural management, overgrazing, deforestation, wildfires, land abandonment, intense road construction and other construction activities. The forecasted increase of intensive rainfall events and prolonged drought periods due to climate change, will enhance surface runoff and sediment transport capacity. The objective of this study was to develop new tools to help land managers mitigate erosion in the country of Greece. One of the tools was a new sensor (ASEMS) that is based on the physical properties of ultrasound to detect erosion locally with great accuracy (1 mm), while simultaneously measuring precipitation, soil moisture, and soil and air temperature. The other tool was the development of the Soil Erosion Integrated Information System (SE-I2S) that enables land managers through a series of questions to understand if they are facing erosion problems and what type of erosion. This tool can be applied to large areas. Overall, both new tools are user friendly and help land managers mitigate soil erosion cost-effectively.

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1. Introduction

Soil erosion is one of the most serious threats worldwide [1] because of the multiplier effects it can have on society (decrease in food production, environmental problems etc.). The exponential increase of the world's population has led to the transformation of naturally vegetated area into agricultural (because of the need to increase food production) and urban areas (areas to house people). These anthropogenic activities have increased soil erosion rates that substantially exceed soil formation rates [2, 3]. Pimentel and Kounang [4] reported that 75 billion metric tons of soil are removed yearly, primarily from agricultural lands. Consequently many scientists consider soil erosion as serious a threat as climate change.

Soil erosion can cause many and diverse problems. The most obvious is the loss of the fertile topsoil of agricultural areas that ultimately decrease its productivity [5, 6]. As a result more fertilizers are used thus increasing food cost or in the worst case the lands are abandoned. With 99% of the world food coming from the soil [6] its protection is a necessity in association with the exponential growth of the world's population.

Excessive soil erosion also leads to the siltation of streams and lakes, eutrophication of surface water bodies, loss of aquatic and land biodiversity, land degradation and desertification [6,7]. Soil erosion threatens the sustainability of natural and water resources as well as the environment.

The Mediterranean region has been inhabited by humans for thousands of years and many believe that it has been impacted by humans more than any other region [8]. In addition, it is a semi-arid and arid region that limits vegetation growth and cover making it even more susceptible to erosion. Soil erosion rates can be very high since large areas on steep slopes with fragile soils have limited vegetation cover, while the long dry periods make them even more vulnerable to intensive erosive rainfall events [9, 10, 11]. In addition, socio-economic changes during the past century in the region has led to the frequent abandonment of agricultural fields that can be heavily impacted by erosion [12]. Finally, the frequent wildfires that this region experiences also exacerbates soil erosion [13]. Conservation measures should be a priority in order to maintain sustainability, especially in areas that are subject to inappropriate agricultural practices, overgrazing, deforestation, wildfires, land abandonment, intense road construction and other construction activities [14, 15].

Another important issue that should be considered is the forecasted climate change for the Mediterranean region. It has been forecasted that precipitation intensities will increase [16] that should lead to higher surface runoff volumes and increased sediment transport capacity. In addition, prolonged droughts have also been

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forecasted [16] that should reduce vegetative cover and increase soil crusting, thus enhancing surface runoff. Drought in conjunction with other anthropogenic activities can increase soil crusting [17]. Overall, climate changes will enhance soil erosion in the Mediterranean region where it already is a serious threat [16].

A key priority for the European Union is the protection of soils from erosion and this has been recognized within the Soil Thematic Strategy of the European Commission [18, 19]. It has also been estimated that the financial cost of soil erosion is several billion Euros per year. In Greece, despite more than 1/4 of the country's total land area experiencing severe soil erosion [20], minimal systematic and holistic efforts have been done to reduce this major environmental problem.
Currently most surface erosion methods measure change in surface level or volume [21, 22]. Common methods include erosion pins, profile meters, catchpits. While these method are inexpensive and easy to use it is not easy to take frequent measurements. Typically the measurements are monthly, seasonally, or even yearly. Field plots have also been used with mixed results but can be very expensive and time-consuming. In general continuous measurements would provide greater insight in erosion processes while increasing the accuracy of measurements would allow land managers to implement cost-effective best management practices using on science-based information.

The objective of this study was to enhance the reduction of soil erosion in Greece. This was achieved by developing new tools for land managers to help mitigate soil erosion more effectively. Specifically, two new tools were developed. One tool measures erosion very accurately at a specific location while the other is a system that can be applied to a broader area to indicate soil erosion risk and soil erosion type.

2. Study Area

The selected study area was the island of Thasos because while occupying a small area it has a wide range of precipitations, slopes, vegetation types and land-uses that all are critical parameters for surface soil erosion. Thus, Thasos Island provides an excellent field laboratory to study soil erosion for the Mediterranean region.
Thasos belongs to Kavala prefecture and Macedonia Region and is the most northern Greek island (Fig. 1). The terrain is mountainous while the climate is characterized as Mediterranean (Fig. 1). The average annual temperature is 15.8^{o}C, the average annual precipitation is 770 mm and the highest mountain peak reaches 1,203 m [23].

At the same time because this is a Mediterranean ecosystem it very susceptible to wildfires (part of its ecosystem). The island has experienced many severe wildfires in the past with almost 3/4 of the island's forest being burnt in the past [24]. Overall, the protection of the island's natural environment is imperative. Unfortunately, the existing fire fighting planning, along with its geomorphology, fire-sensitive woody species, large population concentration during the summer months and lack of modern infrastructures and services, present major issues in the ineffectiveness of preventing, protecting and suppressing forest wildfires on the island. This is another reason for selecting this particular island, since one of the major post-wildfire problems are surface erosion and torrent flooding, even years after the fires have occurred. These erosion problems are still evident in many areas of the island (Fig. 2) [23]. Finally, while there is a substantial amount of published work regarding Thasos wildfires, there is no information related to post-wildfire effects on factors such as soil erosion [25]. More research related to post- wildfire effects should help better assess the negative impacts of soil erosion.

3. Research Activities

The research activities focused on two different spatial scales. The one scale was at a specific point with a sensor being developed that measured soil erosion accurately but also helped understand the condition (mechanisms) that soil erosion occurs. The other research activity focused on a much larger scale and this tool was online. Specifically, this tool allowed land managers to

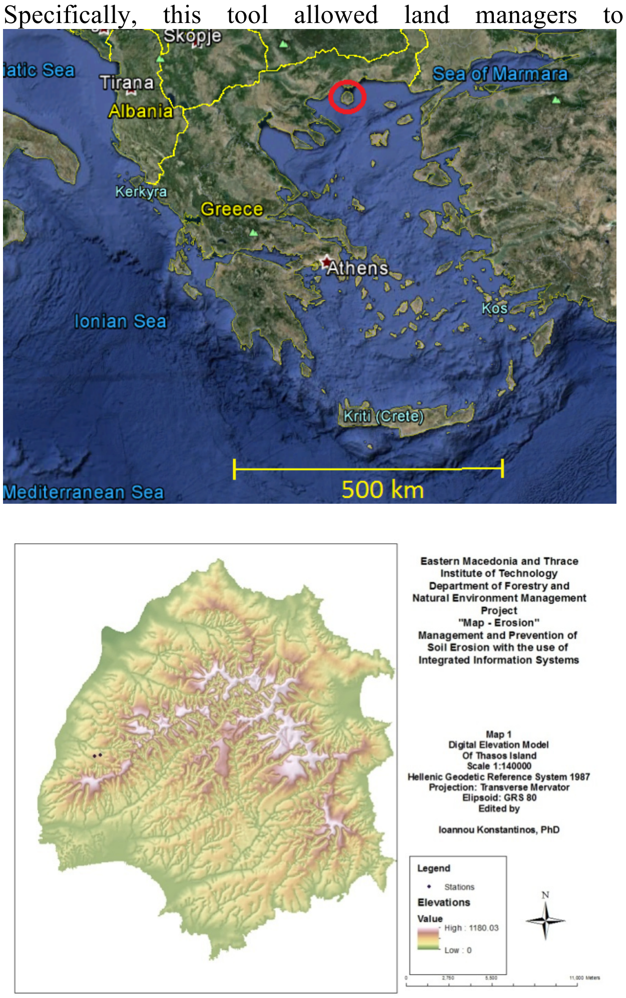

Fig. 1. Thasos Island was the study area. It was selected because of its topographic and vegetative diversity. The location of Thasos Island in Greece (top). The two black dots depict the location of the ASEMS sensors on the Digital Elevation Model (DEM) of Thasos (bottom).

Fig. 2. Severe rill (top) and stream bank and bed (down)

3.1 Digital Geodatabase

Today's society is based on information. Information is essential to solve problems, especially environmental problems that are dependent on many factors. This is why spatial data for Thasos Island were created and are available in electronic format. The data are freely available as a digital geodatabase at the project website www.map-erossion.eu in the study area section. The spatial data created were: topography, stream network, watershed boundaries, land-uses/land cover and soils.

3.2 Automated Soil Erosion Monitoring System (ASEMS)

The epidodic nature of soil erosion requires continuous measurements for its more acurate evaluation and comprehension [27]. Most commonly used erosion techniques cannot measure continuously (typically either monthly, seasonally or yearly), although some new techniques have been developed that measure semi-continuously or continuously [27, 28]. Soil erosion is also heavily infleunced by many different variables such as precipitation and soil moisture. To fully comprehend soil erosion it is also essential to measure these variables. Measuring such variables would allow to understand the erosional processes and help lead to the adoption of more effective soil erosion conservation practices.

To accomplish this, the setup that was developed exploited the use of a data logger (data acquisition system) and the physical properties of ultrasonic signals for erosion measurements. Ultrasonic signals can acurately scan the surface of objects [29]. The tool that was developed is called the Automated Soil Erosion Monitoring System (ASEMS). The datalogger has four sensor arrays that measures soil erosion, precipitation, soil and air temperature and soil moisture (Fig. 3). The sensor array that measures soil erosion emits an ultrasound signal. The signal (essentially a wave) is emitted from the sensor and afterwards it is reflected on the soil surface and returned to the sensor array. The time between the emission and reception is measured by the datalogger. Based on the time it took and the constant of the speed of sound it automatically calculates the surficial erosion. An erosion event leads to an increase of the time while a depositional event leads to a decrease in this time. The additional three sensor arrays include a precision rain gauge, soil moisture and temperature sensor and air temperature sensor. Precipitation is the main cause of overland flow ersoion. Soil moisture is also a critical factor for soil erosion [30, 31]. Another innovation is that the logging frequency provides a dual rate recording (a.k.a. accelerated logging). This is a very important feature because it allows the datalogger to change (shorten or lengthen) the measurement time interval for specific variables (e.g. soil moisture, soil erosion), when triggered by a predefined variables (e.g. rainfall). In this study the year around measurements by the 4 sensors are every hour. Since erosion is typically episodic and does not occur gradually [27], when certain variables are triggered and in our case precipitation, the recording increases to every minute. Overall, these measurements are done in a fully automated way by the station's datalogger and this data can accessed remotely without having to visit the study area. Solar panels provide the required energy for the sensors and data loggers, even during their operation at night (Fig. 3). Finally, the data loggers and the 4 sensor arrays used are commercially available, while the construction of the ASEMS is resistant to exposure at external environmental conditions.

Only two sensors setups were developed, so sites with different erosion rates were selected. Using GIS and Multi-criteria Decision Analysis (MCDA) the erosion risk of the areas of the island was determined. This combination has been used successfully for the identification and resolution of a wide variety of environmental problems including erosion [32, 33, 34]. For the final selection of the sites, field surveys took place, keeping in mind that different local environmental parameters may provide different erosion results. Specifically, one of the sites had limited vegetation cover and was on a steep slope (high erosion rates), while the other had good vegetation cover and a gentler slope (minimal erosion rates) (Fig. 4). To check the acuracy of the measurements recorded by the sensor, erosion pins (one of the most common erosion measuring techniques) [28] were placed adjacent to the sensors. Current results indicate very good results only for surface erosion but with certain modifications ASEMS could be applied for rill and gully erosson. In addition, because of the cost of the ASEMS they should be placed strategically. They should be placed in representative erosional areas of the study region.

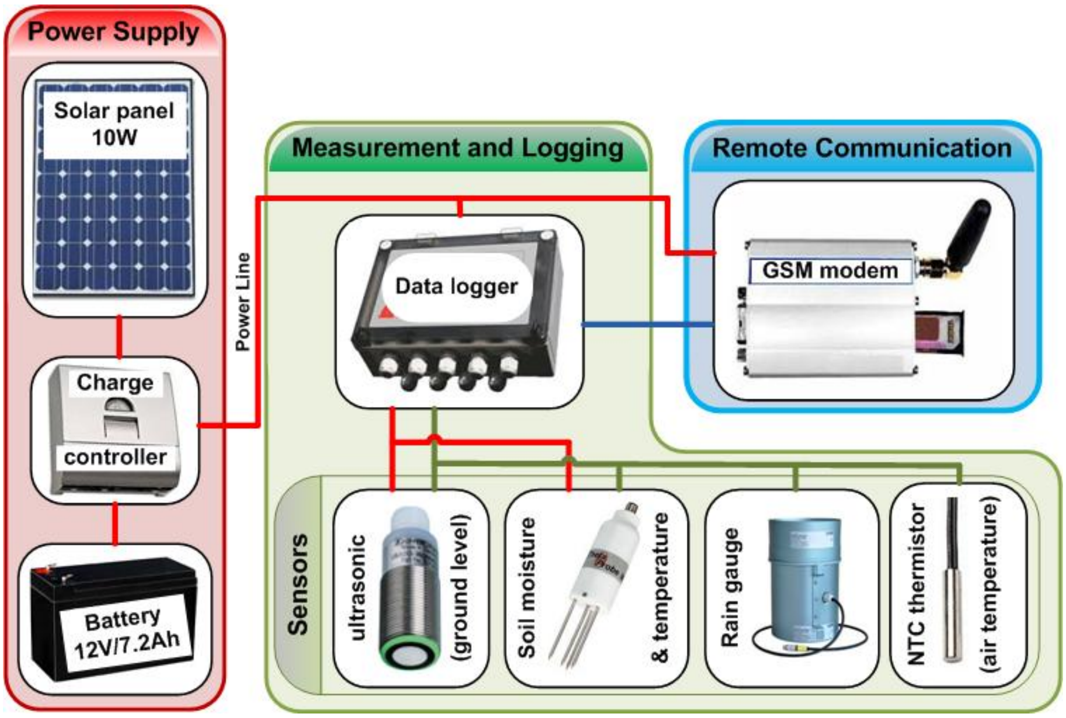

Fig. 3. The block diagram of the sensor with the power supply, the management system, the remote communication and the four sensors.

Fig. 4. The location of the two ASEMS. One was located under vegetation with gentle slopes (top)

3.3 Soil Erosion Integrated Information System (SE-I^{2}S)

The many factors that need to be considered for environmental problems require the analysis of extensive amounts of data in order to find effective and sustainable solutions. Decision Support Systems (DSS) have the ability to handle large amounts of data. This has led to many researchers using them extensively to help managers in environmental decision making process of environmental problems. Specifically, DSS have been used in geotechnical applications [35], fire occurrences [33] and air pollution control [36].

The DSS in our case is the Soil Erosion Integrated Information System (SE-I^{2}S) that considers the major parameters that affect or cause soil erosion and presents the best managerial practices for soil erosion prevention. The analysis of these parameters is implemented through a Multi-Criteria Decision Analysis (MCDA). This type of analysis allows the expression of qualitative parameters as quantitatively and provides a more comprehensive analysis. Data collected from an extensive literature review [37], along with the information from local stakeholders by an electronic questionnaire regarding the mechanisms that create soil erosion were the inputs of the DSS. Another literature review on soil erosion best management practices carried out by the authors was also incorporated in the DSS.

The DSS consists of the three subsystems. i) The Data Management Subsystem. This subsystem consists of the database and the database manager. ii) The Model Management Subsystem that contains the models and provides the DSS with its analyzing potential. In addition, it also includes the model building languages. iii) The Knowledge Subsystem. It provides the required knowledge, which supplements the knowledge of the decision-maker. iv) The User Interface Subsystem. It is the subsystem that is responsible for the communication between the user and the DSS and it is completely implemented by using World Wide Web technologies.

When all phases are completed, the final result is the Integrated Information System itself [38]. The final SE-

I^{2}S is easily accessible and available to everyone through our project's website www.map-erossion.eu by selecting the link «Expert System» (Fig. 5). This transfers the user to a sub-page where the SE-I^{2}S is located (Fig. 5).

In this study the «Expert System» was used. The entire system was programmed locally by using a special tool created by expertise2go, and then it was uploaded using an FTP server to the website. The system was afterwards integrated with a dynamic web page which was created using, a well-known Content Management System.

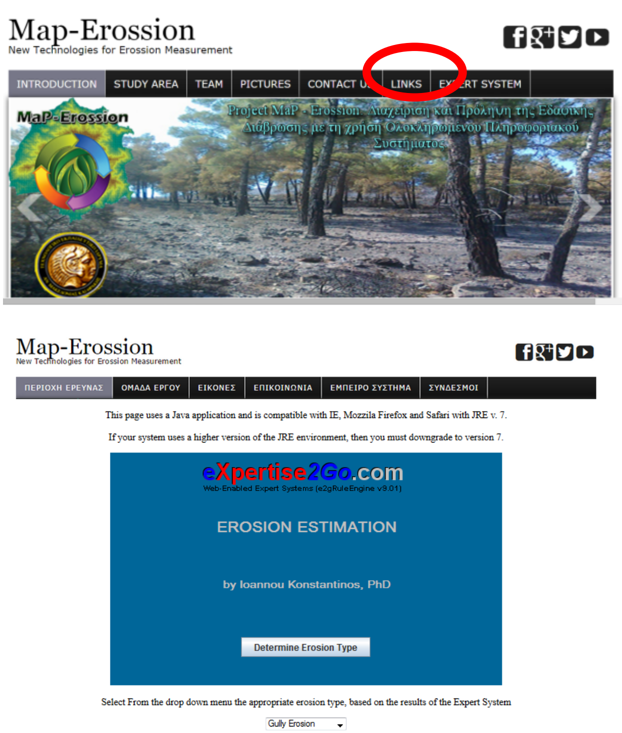

Fig. 5. The link "Expert System" on the project website (top) and first page of the expert system (bottom)

To run the SE-I^{2}S the user selects the button «Determine Erosion Type» to start determining the erosion type. Four rules were created, one for each erosion type. The types of erosion were raindrop, sheet, rill and gully. The created rules for the erosion have the form presented in Fig. 6, where the splash erosion rule is presented. The "if" command used in this rule, have values which were determined from the user, when he/she answered the previous questions. The system moves onto the next question, based on the type of the answer provided by the user, along with the certainty of the answer. During the design phase of the system, a mechanism which can interpret the results was embedded. After the determination of the erosion type by the system, the user can select one of the available erosion types. Afterwards the SE-I^{2}S can provide more information regarding the best management practices that he/she must apply in order to mitigate soil erosion in the region.

CONDITIONS	SPLASH EROSION
1	true
2	–
3	false
4	–
5	–
6	false
7	–
8	–
9	false
10	–
11	false
ACTIONS	
EROSION TYPE IS:	RAINDROP
	–
	–

Fig. 6. The created rules for splash erosion. Similar conditions were developed for all 4 types of erosion.

A major innovation is that SE-I^{2}S is online because it allows users to access it from everywhere they can have internet access, allowing them to find solutions wherever they are and whenever they want. Also, web access eliminates the need for special software and hardware requirements to be used, since SE-I^{2}S can be used with any computer or hand held device regardless of its operating system, its processor memory and storage capabilities.

4. Conclusions

More efficient and effective reduction of soil erosion can be implemented by the appropriate authorities in Greece through the utilization of new innovative tools that were developed. Specifically, a new sensor ASEMS was developed that measures accurately and continuously soil erosion at a specific location along with other parameters that influence erosion and erosion processes.

The SE-I^{2}S tool can be used for much larger scales and through a series of question can help land managers find the type of erosion in an area. In addition, the recommended best management practices are provided. Finally, this tool is online and easily accessible.

Overall, both new tools did not previously exist in Greece and will help land managers in the holistic management of soil erosion in the country. The tools are user friendly and help land managers complete their jobs cost-effectively e.g. place soil erosion conservation practices were the need is the greatest (areas with high soil erosion potential). At the same time, these tools provide easily understandable, scientifically sound data to the decision makers but also to the general public.

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